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Delivery-Water Heaters Used in Cogeneration Steam Turbine Units Produced by Ural Turbine Works

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Abstract—The designs of horizontal delivery-water heaters used as part of steam-turbine units equipped with the cogeneration turbines developed at Ural Turbine Works are described. The design features of the apparatuses relating to the specific nature of their operation as part of combined-cycle plants equipped with cogeneration turbines are pointed out.

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The heating installations used as part of large cogeneration turbines of Ural Turbine Works (UTZ) comprise type PSG horizontal delivery-water heaters, the unique design of which was developed by UTZ specialists.

The design of delivery-water heaters has undergone essential changes as existing turbines manufactured at UTZ were refined and new ones were developed. The first 25 MW turbines manufactured at Turbine Engine Works (the former name of UTZ) according to drawings developed at Leningrad Metal Works (LMZ) were equipped with vertical delivery-water heaters (boilers). Steam taken from the chambers of the turbine's heating extractions at a pressure higher than the barometric level was used as heating medium in them. The Turbine Engine Works specialists who developed a turbine unit equipped with a VPT-25-4 turbine (constructed in 1957) succeeded in considerably improving the economic efficiency of this unit (by 7.7% during operation in the condensing mode and by 10–18% during operation in the cogeneration mode). This was achieved due to a number of improvements, among which was the use of reduced pressure in the heating extraction equal to 0.07 MPa. This, however, entailed the occurrence of problems relating to the need of removing air inleakages from the vertical boilers during their operation in rarefaction modes and with high pressure drops in inlet pipelines that were due to increased volumetric flowrates and velocities of steam in them. These circumstances generated a need to search for new solutions aimed at increasing the free flow cross sections of inlet pipelines and shortening their length by placing the apparatus closer to the steam source (i.e., the turbine), efficiently removing steam–water mixture from apparatuses operating under rarefaction, and developing an essentially new design concept for heat exchangers of this type and purpose [1].

Among the solutions that were adopted in the designs of next turbines produced by Turbine Engine Works, including the VPT-50-4, VT-50-1, and VT-100-1 turbines, which were issued in 1959, 1960, and 1961, respectively, were the use of a two-staged scheme for heating delivery water and utilization of the heat of steam entering into the condenser, e.g., for preheating of delivery water. The Turbine Engine Works specialists who developed the projects of these turbines substantiated the advisability of further reducing the steam pressure in the turbine's lower district-heating extraction. The use of a system for two-staged heating of delivery water, as well as utilization of the heat of steam entering into the condenser during turbine operation in the cogeneration mode were new ideas in turbine construction, and effort toward implementing them involved overcoming of certain difficulties and development of new intricate design solutions. These solutions were found as Turbine Engine Works specialists developed the apparatuses for turbines containing two heating extractions of steam and extended the adjustment ranges of pressure in them equal to 0.05–0.20 MPa in the lower and 0.06–0.25 MPa in the upper district-heating extractions.

The designs of heaters having a heat-transfer surface several times larger in a single apparatus were developed for new turbines in the period from 1958 to 1960. Horizontal boilers with surface areas equal to 840, 1300, and 2250 m^2 were constructed for the first stage of heating delivery water, and vertical boilers with surface areas equal to 850 and 1350 m^2 were constructed for the second stage of heating. The changeover for using horizontal apparatuses, which were designed specifically for being placed in the foundation openings right under the turbine, made it possible to locate them at the closest distance to the steam extractions, shorten the length of inlet pipelines, and reduce the loss of pressure in them (a feature especially important during turbine operation with the pressure in the lower heating extraction below the barometric level), as well as to decrease the machine hall area required for placing the apparatuses. However, the dense layout resulting from

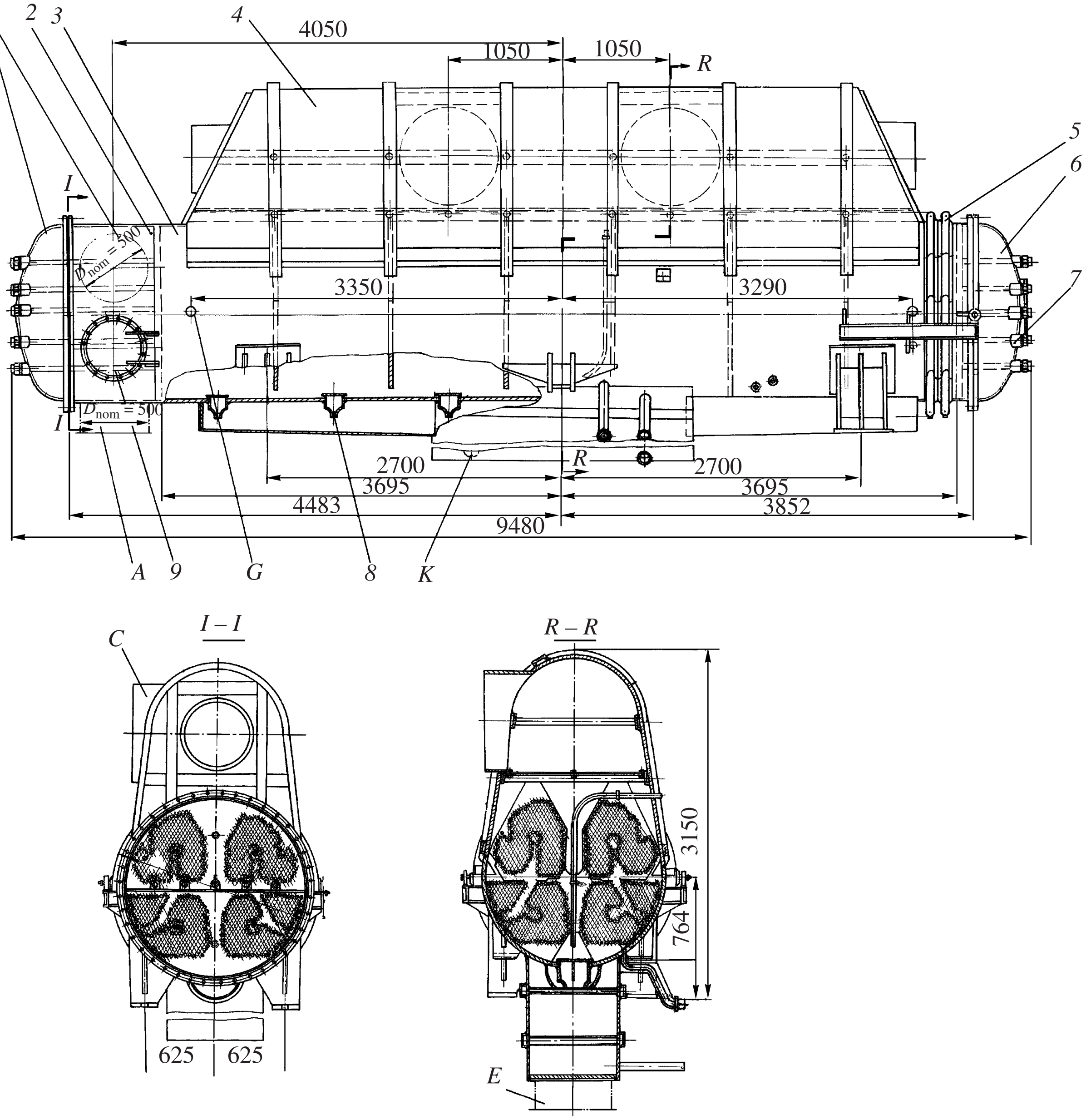

Fig. 1. The BG-840 delivery-water heater. (*A*) is the inlet of network water, (*B*) is the outlet of network water, (*C*) is the steam inlet, (*E*) is the outlet of steam condensate; (*G*) is the removal of steam–air mixture; and *K* is the drain of condensate from the boiler; (*1*) is the cover of the front water chamber, (*2*) is the front water chamber, (*3*) is the heater shell, (*4*) is the steam receiving chamber, (*5*) is the lens compensator, (*6*) is the turning water chamber, (*7*) is the anchor brace, (*8*) is the condensate drain funnel, and (*9*) is the manhole.

the placement of horizontal apparatuses within the confines of the foundation excludes the possibility of installing stop valves in this space and, which is especially important, of back valves. The latter problem was solved by introducing special conoidal fittings (funnels) in the design of heaters [2], due to which condensate flows down to the hot well due to gravity with the minimal head, and steam that is sometimes generated in the hot well as condensate flashes in it when the turbine load is rejected is prevented from being discharged.

The tube bundles of BG-840 (Fig. 1) and BG-1300 horizontal boilers are made similar to the tube bundles of condensers with a vertical central passage for steam, two lateral tube sections, and removal of steam–air mixture after air coolers through the fittings made in the apparatus lateral walls. A receiving chamber is made above the tube bundle over all its length for receiving steam, which is fed to the chamber on its lateral side via two pipelines with D_{nom} = 900 mm for the BG-840 heater and D_{nom} = 1000 mm for the BG-1300 heater.

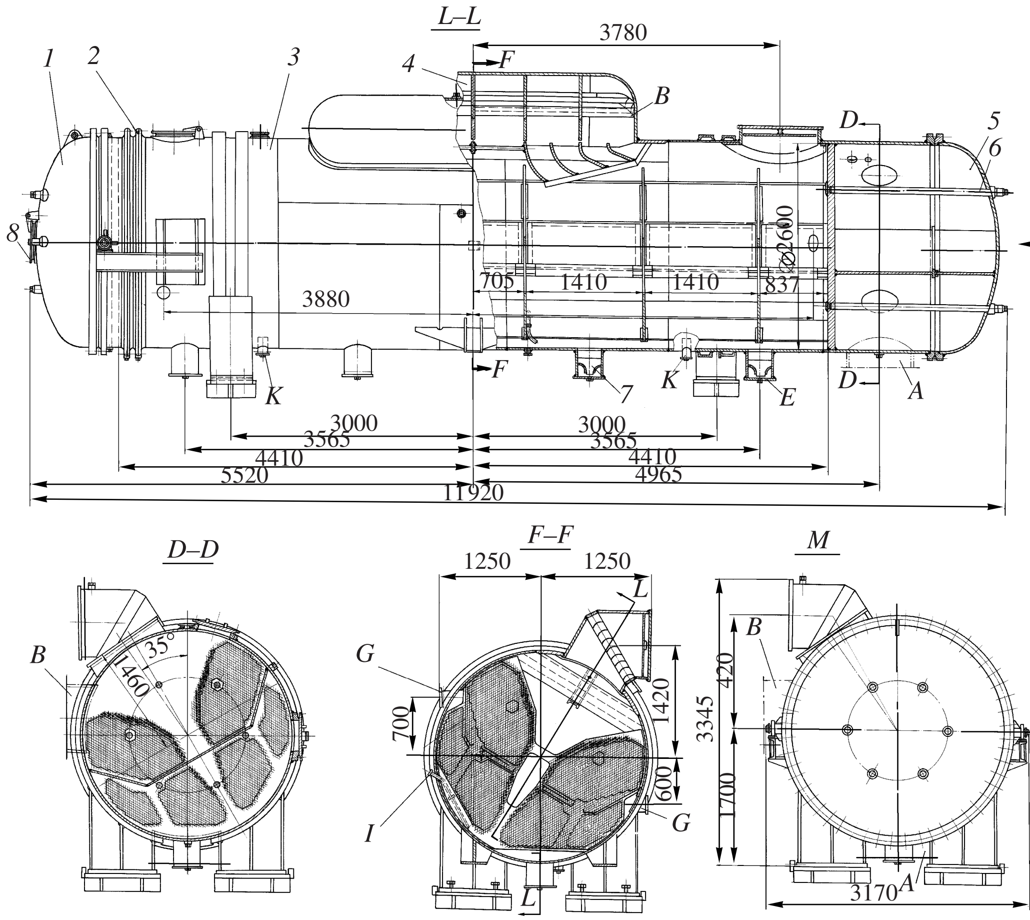

Fig. 2. The BG-2250 delivery-water heater. (*I*) is the tap to the water level indicator; (*1*) is the turning water chamber, (*2*) is the lens compensator, (*3*) is the heater shell, (*4*) is the steam receiving duct, (*5*) is the inlet (front) water chamber, (*6*) is the anchor brace, (*7*) is the condensate drain funnel, and (*8*) is the manhole. The other notations are the same as in Fig. 1.

Type BG-2250 horizontal boilers (Fig. 2) were developed for the first stage of delivery water heating in VT-100-1 turbines, and two BV-1350 vertical boilers were used as the second stage. Heating steam was fed to the BG-2250 horizontal apparatuses, unlike how it was done for BG-840 and BG-1300 apparatuses, through a duct with a cross section equal to 800×4000 mm, the width of which corresponded to the distance between the lateral tube sections in the inlet cross section of the central passage.

Each steam supply pipeline and duct that connects the heaters to the heating extractions of steam from the turbine is furnished with lens compensators placed in accordance with the three-hinge arrangement, the use of which allows spatial thermal expansions to be reliably compensated for.

Modern turbine units produced by UTZ are made only with type PSG horizontal delivery-water heaters [1, 3, 4], the first-stage of which (PSG-1) is placed under the turbine, and the second stage (PSG-2), under the generator.

The hut output of delivery-water heaters used in cogeneration turbines is determined by the district-heating load, the parameters of steam in the heating extractions from the turbine, and the flowrate of water in the heat network. Two main heaters are installed for each turbine or unit, and the heat capacities of each are selected so that the PSG-1 apparatus alone can cover 100% of heat load if the upper heating extraction and PSG-2 are disconnected.

UTZ's modern horizontal delivery-water heaters with heat-transfer surface areas ranging from 800 to 5000 m^2 are designed to operate at excess pressure in the water circuit and in the range from rarefaction to excess pressure in the steam circuit. The heaters have all-welded shells made jointly with water chambers and a central tube bundle assembled of straight tubes, the ends of which are fixed in tube sheets by rolling. The tubes rest on intermediate partitions, which are installed in such a way that dangerous modes of their vibration are avoided. Temperature expansions that occur in the shell are compensated for by means of lens compensators and due to the fact that one of two saddle supports installed on the side of the turning water

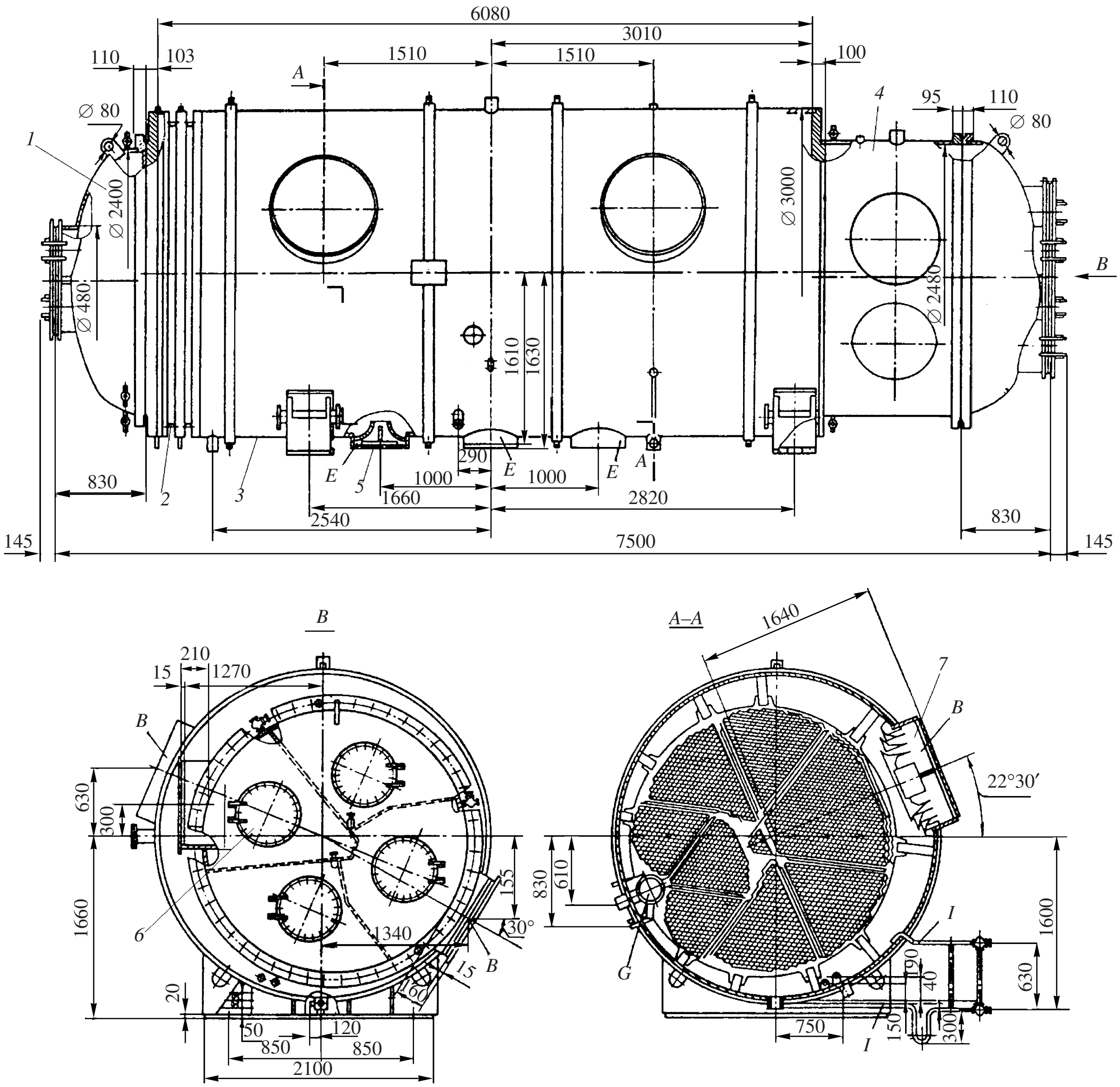

Fig. 3. The PSG-2300-2-8-I delivery-water heater for UTZ's T-110/120-130 turbine. (*1*) is the turning water chamber, (*2*) is the lens compensator, (*3*) is the heater shell, (*4*) is the inlet (front) water chamber, (*5*) is the condensate drain funnel, (*6*) is the manhole, and (*7*) is the concentric splitter. The other notation is the same as in Figs. 1 and 2.

chamber is made as a movable one. The water chambers have removable covers and are furnished with hatches through which the tubes of heat-transfer surface can be inspected, cleaned, blanked off, and replaced. The heaters are supplied and transported as fully ready-made equipment. The scope of work to be done in situ includes connection to the hot well, welding of external pipelines, and carrying out hydraulic tests of the steam and water spaces.

Figure 3 shows the *design of a PSG-2300-2-8-I horizontal delivery-water heater* having a heat-transfer surface area of 2300 m^2 for the T-110/120-130 cogeneration turbine unit and designed for operation at pressures of heating steam in the turbine's lower heating extraction ranging from 0.03 to 0.2 MPa in the case of using a two-stage heating arrangement and 0.05 MPs in the case of using a one-stage heating arrangement and at the pressure of network water equal to 0.8 MPa. The minimal and maximal flowrates of network water are equal to 1700 and 4500 t/h, which corresponds to the range of water velocities in tubes from 1.0 to 2.6 m/s. If the velocities of water are lower than 1 m/s, formation of deposits on the inner surfaces of tubes becomes more intense and their fracture due to corrosion under deposits becomes more probable. If the velocities are higher than 2.6 m/s, the oxide film is washed out at the inlet sections of tubes and their fracture due to erosion–corrosion wear becomes more probable.

Heating steam from the turbine's heating extraction enters into the apparatus through cylindrical fittings, inside which rotary concentric heads are installed, by means of which steam flow can be turned and distributed uniformly along the tube bundle. The tubes of the heat-transfer surface are additionally protected from the impact of direct steam flow by installing blanked-off steel tubes in the peripheral rows. The tube bundle is placed in the heater shell with some eccentricity, a solution that allows a symmetrical wedge-shaped distributing manifold embracing the bundle to be constructed in the zone adjacent to the location at which steam is admitted. Steam–air mixture is removed from the heater through perforated manifold G, which closes the air coder that is separated in the first-pass tube bundle for condensation and cooling of mixture. The manifold for removing steam–air mixture is similar in design to the corresponding device used in the UTZ condensers and has the same ratio of free flow cross-section areas [5]. The circuit solution for removing steam–air mixture and draining the header used in the air removal system is shown in Fig. 4.

Heating-steam condensate flows down into the shell's lower part and from it to the hot well through specially profiled conoidal fittings (funnels). The level of condensate in the steam space is monitored using level gages and sensors for remote monitoring.

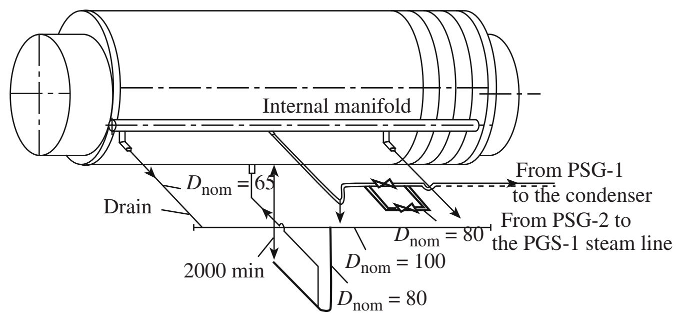

Fig. 4. Circuit arrangement for removing steam–air mixture and draining the suction system manifold.

A new standard-size series of delivery-water heaters has been developed at UTZ for a network water pressure equal to 1.14 MPa, with the appropriate changes made to the design of water chambers used in these apparatuses. A standard-size series of apparatuses for the water pressure equal to 1.6 MPa is being developed (Fig. 5). One apparatus of this series (a PSG-2200 heater) has already been manufactured and installed at a cogeneration station.

The main technical data of all standard sizes of type PSG delivery-water heaters that are presently manufactured at UTZ are given in the table.

Table

Standard size	Heat-transfer surface area, m^2	Design pressure, MPa (gage)		Working parameters								Design heat flux, 10^{-6} W		Design pressure drop across the water space for clean tubes, MPa	
				Heating steam				Heated network water							
		in the steam space	in the water space	Pressure, MPa (absolute)	Maximal inlet temperature, °C	Flowrate, t/h: rated	Flowrate, t/h: maximal	Maximal inlet temperature, °C	Flowrate, t/h: rated	Flowrate, t/h: maximal	Flowrate, t/h: minimal	rated	maximal	rated	maximal
PSG-800-3-8-I	800	0.3	0.78	0.03–0.25	250	58	116	120	1500	2000	1250	34.9	69.8	0.035	0.084
PSG-1250-3-11.4-II	1250	0.3	1.12	0.03–0.25	250	90	220	127	2000	3000	1200	54.0	134.0	0.038	0.082
PSG-1300-3-8-I, II	1300	0.3	0.78	0.03–0.25	250	90	230	123	2300	3000	1200	54.0	140.0	0.052	0.084
PSG-2200-2-16-I	2200	0.2	1.57	0.03–0.23	250	170	345	123	3500	4500	1700	102.0	209.0	0.069	0.110
PSG-2200-3-16-I	2200	0.3	1.57	0.06–0.25	250	170	225	127	3500	4500	1700	102.0	135.0	0.069	0.110
PSG-2300-2-8-I	2300	0.2	0.78	0.03–0.20	250	170	360	123	3500	4500	1700	101.8	203.0	0.063	0.100
PSG-2300-3-8-II	2300	0.3	0.78	0.06–0.25	250	170	240	127	3500	4500	1700	101.8	145.0	0.063	0.100
PSG-3000-3-11.4-I	3000	0.3	1.12	0.06–0.25	250	180	235	124	3500	5000	1900	113.0	143.0	0.058	0.110
PSG-3000-3-11.4-II	3000	0.3	1.12	0.03–0.22	250	180	355	124	3500	5000	1900	113.0	215.0	0.058	0.110
PSG-4900-2.2-11.4-II	4900	0.22	1.12	0.06–0.20	300	310	645	120	6000	8000	2600	204.0	419.0	0.110	0.180
PSG-5000-2.5-8-I	4950	0.25	0.78	0.03–0.15	300	310	645	115	6000	8000	2700	204.0	419.0	0.098	0.165
PSG-5000-3.5-8-I	4950	0.34	0.78	0.06–0.20	300	310	430	120	6000	8000	2700	204.0	279.0	0.098	0.154
PSG-5000-3.5-8-II	4950	0.34	0.78	0.06–0.30	250	270	540	129	6000	7200	2700	163.0	326.0	0.091	0.129

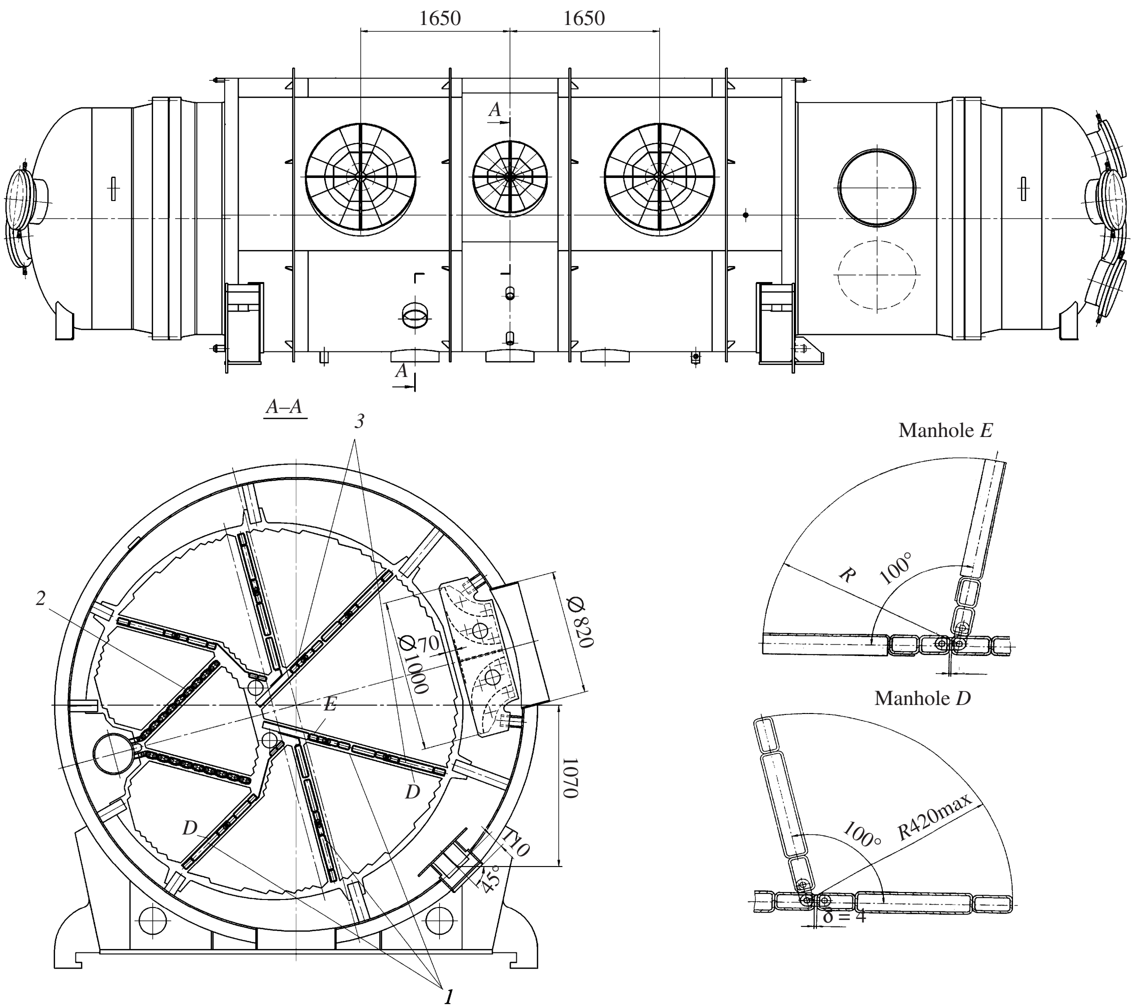

Fig. 5. The PSG-2200-3-16-I delivery-water heater. (*1*) are the steam shields in the shell space, (*2*) are the steam shields of air cooler, and (*3*) are the manholes (*D* and *E*).

Certain improvements have been made in the design of rotary heads installed in the steam receiving fittings, as well as steam shields installed between the tube bundle segments, in order to make the heaters more suitable for repairs involving full or partial replacement of heat-transfer tubes and elimination of troubles in internal elements and systems, and removal of flaws in welded connections in the apparatuses of new standard sizes.

The newly designed turning heads allow steam flow at the heater inlet to be turned through 90°, a feature that made it possible to do without steel baffle tubes in the peripheral rows. The heads are assembled of four segments connected in pars, a solution due to which much less effort is required to withdraw them and install them back if a need arises to use the steam receiving fittings as manholes.

The newly designed steam shields are furnished with hatches (Fig. 5) consisting of longitudinal elements with a duct-shaped cross section. Hatches *D* and *E* are made in all compartments and segments of the tube bundle, except the steam shields that separate the air cooler zone. The steam shields used in the air cooling zone are designed so that they can be subjected to hydraulic tests during operation at a pressure equal to the pressure at which the heater's steam space is subjected to hydraulic tests (0.44 MPa). The internal cavities of these shields are interconnected by a system of longitudinal and transverse channels, which are connected to the tube sheet outer surface on the side of the inlet water chamber through signal sleeves. The tightness of these internal cavities is checked by connecting them with the atmosphere when the apparatus operates in the modes in which the absolute pressure of steam in its shell space is within the range from 0.06 to 0.14 MPa. If poorly sealed places are revealed in the cavities being checked, these places are sealed by supplying conden-

sate to them at a pressure that exceeds the pressure in the apparatus shell space in the current mode of its operation by not more than 0.15 MPa. Condensate is removed from the cavities into an open funnel.

The surfaces of the intertube space of apparatuses with nonwithdrawable tube bundles cannot be visually inspected in the course of technical examinations. Therefore, the thicknesses of walls inaccessible for visual examination are checked by means of the ultrasonic method with the use of instruments that allow wall thickness to be measured with accuracy of ±0.1 mm. Examination using ultrasonic thickness measurement techniques must be carried out at 29 annular sections for steam barrels, at four annular sections for each steam-receiving fitting, and at 32 points around each steam-receiving fitting. If a flaw is revealed, measurements must be carried out around it in a grid with 40 mm intervals for a steam barrel and with 20 mm intervals for a steam-receiving fitting.

UTZ specialists are constantly working on improving the design of delivery-water heaters and the technology for designing them. Some developments (replacement of smooth heat-transfer tubes by profiled ones [6], application of an improved method for securing tubes in tube sheets [7], development of elements relating to the system for computer-aided design of delivery-water heaters, and optimization of the system according to which they are placed in the layout of a steam turbine unit [8, 9]) were carried out in cooperation with the laboratory of heat exchangers at the Department of Turbines and Engines of Ural State Technical University (UGTU-UPI) and are already used at present at other turbine construction works, as well at some cogeneration stations in retrofitting heat exchangers used in steam turbine units, including delivery-water heaters.

An analysis aimed at generalizing long-term experience gained from operation of the delivery-water heaters developed and produced at UTZ has shown that these apparatuses feature high efficiency and reliability.

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